

Evaluation of a Simple Proof Test of Planar Ferrite Cores

20 December 2008

Aldrich de la Cruz and David Witkin
Space Materials Laboratory
Physical Sciences Laboratories

Prepared for:

Space and Missile Systems Center
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA 90245-2808

Authorized by: Engineering and Technology Group


20090911254

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED

This report was submitted by The Aerospace Corporation, El Segundo, CA 90245-4691, under Contract No. FA8802-09-C-0001 with the Space and Missile Systems Center, 483 N. Aviation Blvd., El Segundo, CA 90245. It was reviewed and approved for The Aerospace Corporation by G. F. Hawkins, Principal Director, Space Materials Laboratory; and D. C. Marvin, Principal Director, Research and Program Development Office. Col. David E. Swanson was the project officer for the Mission-Oriented Investigation and Experimentation (MOIE) program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

A handwritten signature in black ink, appearing to read "David E. Swanson", followed by the handwritten text "for DES". The signature is written over a horizontal line.

Col. David E. Swanson
SMC/EA

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</small>					
1. REPORT DATE (DD-MM-YYYY) 20-12-2008		2. REPORT TYPE		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Evaluation of a Simple Proof Test of Planar Ferrite Cores				5a. CONTRACT NUMBER FA8802-09-C-0001	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Aldrich de la Cruz and David Witkin				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The Aerospace Corporation Physical Sciences Laboratories El Segundo, CA 90245-4691				8. PERFORMING ORGANIZATION REPORT NUMBER TR-2009(8565)-2	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Space and Missile Systems Center Air Force Space Command 483 N. Aviation Blvd. El Segundo, CA 90245				10. SPONSOR/MONITOR'S ACRONYM(S) SMC	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Ferrites are soft magnetic materials that have a wide range of uses in microwave circuits. Many otherwise flight-qualified parts may have a variety of defects arising from fabrication and handling. A finite-element analysis (FEA) was performed to design a simple proof test for a particular planar ferrite core geometry. A 3-point bend test and three different geometries of 4-point bend tests were modeled to determine the distribution of tensile stress on the bottom of the part. The objective was to generate a minimum stress gradient to achieve uniform stress levels throughout the entire part. The simulations indicate that the largest tensile stress is between 1880 and 1,131 psi. Three-point bend tests conducted on two cores indicated that failure was consistent with predictions of the models. The locations of the failures in the tests render these simple proof tests inappropriate for the specific defects of interest.					
15. SUBJECT TERMS Ferrites, Mechanical testing, Proof testing					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			David Witkin
				11	19b. TELEPHONE NUMBER (include area code) (310)336-6090

Contents

1. Introduction	1
2. Experimental Procedure	3
3. Finite-Element Analysis	5
4. Results	7
5. Conclusions	11

Figures

1. Planar magnetic ferrite core, top surface.	3
2. The core inverted in the 3-point bend testing fixture	4
3. Three-point bend simulation results	7
4. The first 4-Point bend test with top displacement of 0.00053 in., resulting in 0.00056 in. of displacement on bottom center.	8
5. The second 4-Point bend test with top displacement of 0.00042 in., resulting in 0.00056 in. of displacement on bottom center.	8
6. The third 4-Point bend test with top displacement of 0.00025 in., resulting in 0.00056 in. of displacement on bottom center.	9

1. Introduction

Ferrites are magnetic oxide materials that are extensively used in microwave circuit applications. Their magnetic and thermal properties can be varied by altering their chemistry, which is based on iron oxide, by substituting other oxides. Typically, ferrites are produced by milling oxide powders of the desired composition, followed by molding into the desired shape. The final fabrication step is a high-temperature sintering operation that both consolidates the powder and volatilizes any binding agents used in molding.¹

In one current application of interest, ferrite cores are to be mounted to a circuit board using epoxy for use in a high-frequency circuit in a spacecraft power supply. The cores are composed of manganese and zinc oxide in addition to iron oxide (Mn-Zn ferrites).

Recently, a program using these cores switched ferrite vendors to materials having lower porosity and higher intrinsic strength. While several surfaces of the parts are machined after sintering, the bonding surface is used in the as-sintered condition. The new vendor's cores were characterized by grooves in the as-sintered bonding surface that are probably a result of tooling used during molding. In addition, the contractor's criteria for accepting a core as flightworthy includes a maximum size for chips observed on the edges of the cores. The effect of these defects on the strength of the cores is not known. Strength testing of the cores has been conducted,² but those tests stressed different regions of the cores and were used to evaluate bonding. These parts have potential use in multiple programs' hardware, so understanding their mechanical behavior is of great interest.

Finite-element analysis (FEA) was used to evaluate whether a simple proof test could be designed that would estimate the strength of the parts in the presence of these flaws. The benefit of a proof test is that it would both demonstrate the ability of flawed parts to withstand a minimum stress and allow a greater number of parts with these processing and handling flaws to be considered flightworthy. The requirements for a simple proof test were as follows:

- Easy to implement and perform using existing fixtures and test equipment
- The defects of interest would be subjected to tensile stresses, which are the cause of failure in brittle materials.
- The flaws of interest would be placed under sufficient tensile stress to initiate failure: large stress gradients across the tensile surface could lead to failures occurring consistently away from the flaws.

Three- and four-point bend tests could be used to meet the first two criteria, while the results of FEA modeling would be used to judge the tests in light of the third.

¹ Dionne, G. F., "A Review of Ferrites for Microwave Applications," *Proc. IEEE* 63(5), pp. 777-789, 1975.

² Witkin, D. B., Aerospace Technical Report in preparation

2. Experimental Procedure

A planar ferrite core is shown in Figure 1. The length and width of the parts are nominally 0.907 in. and 0.492 in., respectively. The disk in the center of the core has a diameter of 0.314 in. and protrudes 0.099 in. above the flat surface of core. The legs at the ends of the core also protrude 0.099 in. above the surface and measure 0.0615 in. at their minimum width and 0.105 in. at their maximum width. The minimum width of the leg is located in the middle of the part. The top surface of the core is in the as-sintered condition. The tops of the central disk and the legs are all ground to the desired size. The bottom surface of the cores (not visible in Figure 1) is also ground to the desired flatness and part thickness.

Two 3-point bend tests were initially conducted in which the part was supported on two outer rollers positioned under the machined top of each leg, and the load was applied to the center of the part on the bottom machined surface by a third roller (Figure 2). This test put the as-sintered surface in tension. In addition, a deflection gauge was used to measure the downward displacement of the central disk during the test. The ferrite cores failed along the edge where the disc protrudes from the surface of the part at a load of approximately 13 lb, after 0.00056 in. of downward displacement along the surface of the disc.



Figure 1. Planar magnetic ferrite core, top surface.

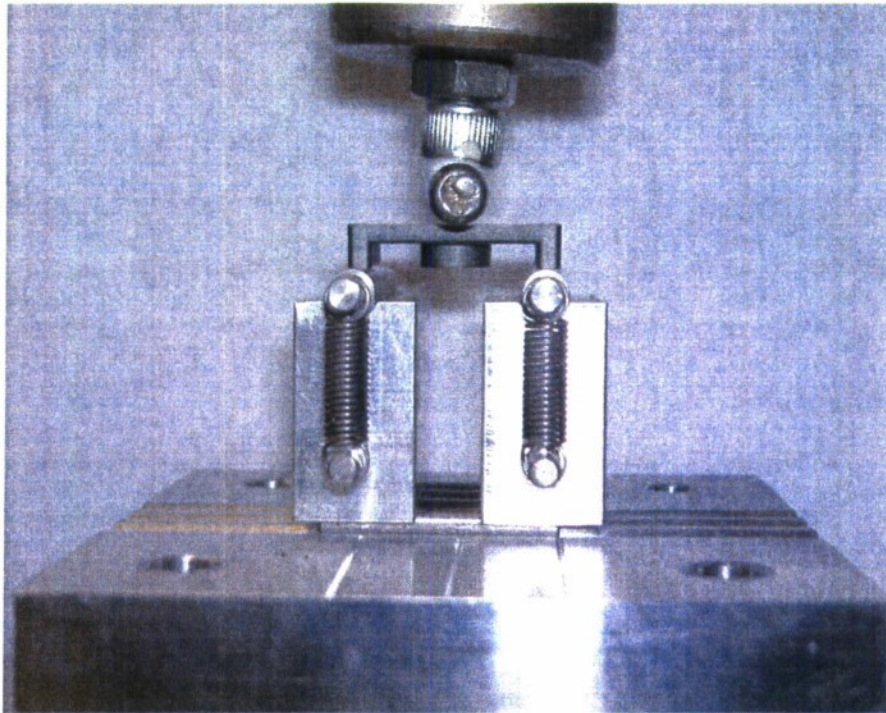


Figure 2. The core inverted in the 3-point bend testing fixture. The top of each leg was supported on a roller, while the load was applied on the bottom surface of the core.

3. Finite-Element Analysis

The experiment was modeled by finite-element analysis. A quarter of the ferrite core was modeled by taking advantage of the problem's two symmetry planes. The ferrite core is made of manganese-zinc ferrite, which has a Young's modulus of 21 Msi and Poisson's ratio of 0.32. As a boundary condition to represent the outer rollers, the center line of the leg is fixed in only the vertical direction. In all cases, the top surface of the ferrite core was displaced to match the displacement that was measured experimentally at the center of the bottom surface of the disc. For the models of the 3-point bend test, the displacement of the top surface was applied at the centerline. For the models of the 4-point bend test, the top surface displacement was applied off the centerline, as mentioned in greater detail below.

4. Results

For the 3-point bend test, a displacement of 0.00059 in. was defined at the top center of the part, which resulted in 0.00056 in. of displacement on the bottom center of the part, as was observed during the laboratory tests. Figure 3 displays a contour plot of the tensile stress on the bottom of the part. The largest tensile stress occurs along the bottom edge of the disc, with a magnitude of 15.0 ksi.

The first 4-point bend test model had the innermost loading line defined at 0.157 in. from the center of the part, which made the span of the two loading rollers equal to the diameter of the central disk. The displacement of the loading line was defined to be 0.00053 in., which resulted in 0.00056 in. of displacement on bottom center. Figure 4 displays a contour plot of the tensile stress on the bottom of the part for the first 4-point bend simulation. The largest tensile stress occurs along the bottom edge of the disc, with a magnitude of 18.8 ksi.

The second 4-point bend test model had the innermost loading line defined at 0.25275 in. from the center of the part, or roughly halfway from the center to the edge of the core. The displacement of the loading line was defined to be 0.00042 in., which resulted in 0.00056 in. of displacement on bottom center. Figure 5 displays a contour plot of the tensile stress on the bottom of the part for the second 4-point bend simulation. The largest tensile stress occurs along the bottom edge of the disc, with a magnitude of 12.5 ksi.

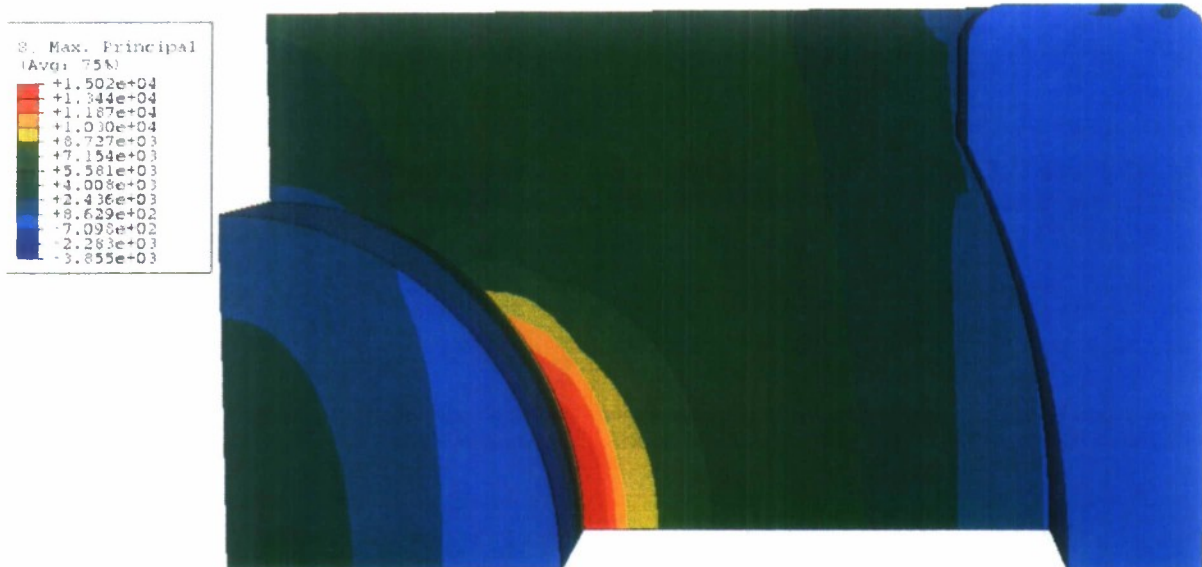


Figure 3. Three-point bend simulation results.

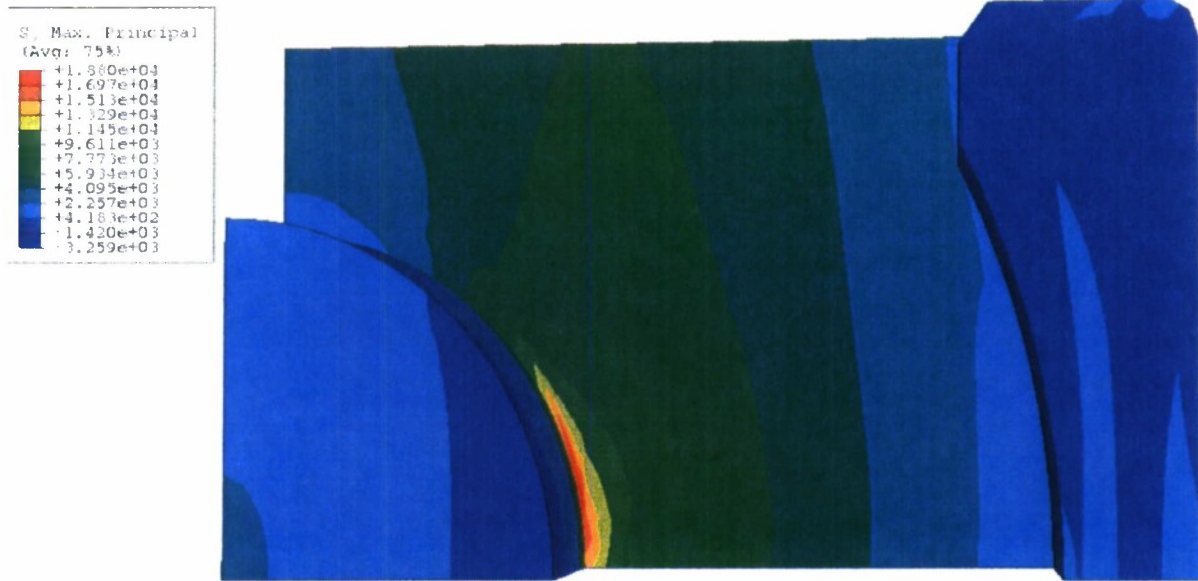


Figure 4. The first 4-Point bend test with top displacement of 0.00053 in., resulting in 0.00056 in. of displacement on bottom center.

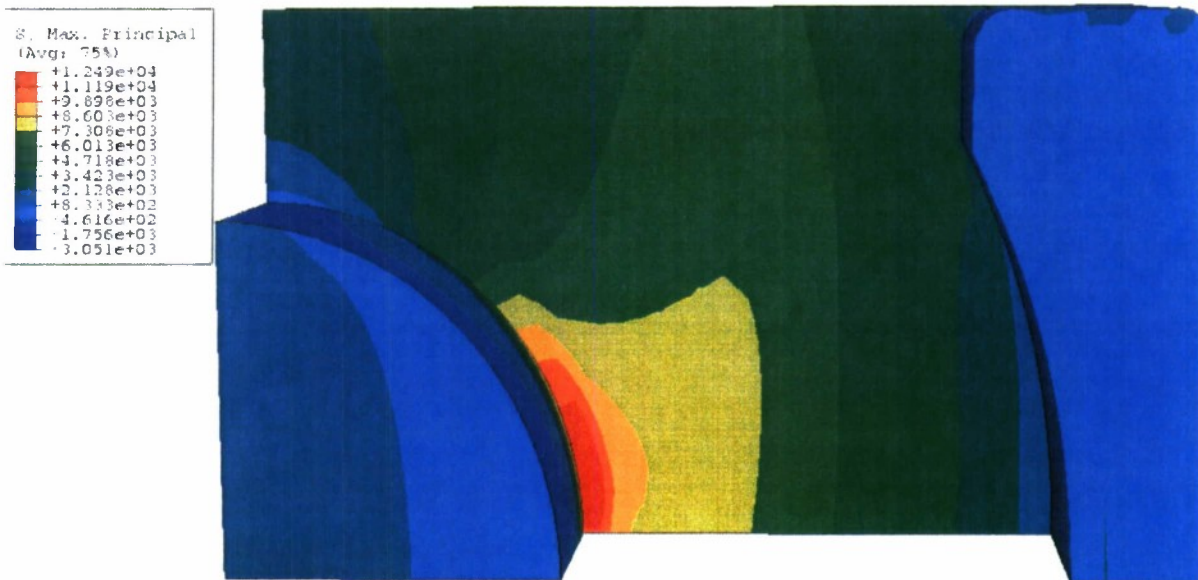


Figure 5. The second 4-Point bend test with top displacement of 0.00042 in., resulting in 0.00056 in. of displacement on bottom center.

The third 4-point bend test model had the innermost loading defined at 0.3485 in. from the center of the part. This placed the loading rollers at the maximum width of the leg. The displacement of the loading line was defined to be 0.00025 in., which resulted in 0.00056 in. of displacement on bottom center. Figure 6 displays a contour plot of the tensile stress on the bottom of the part for the third 4-point bend simulation. The largest tensile stress occurs along the bottom edge of the disc, with a magnitude of 11.3 psi.

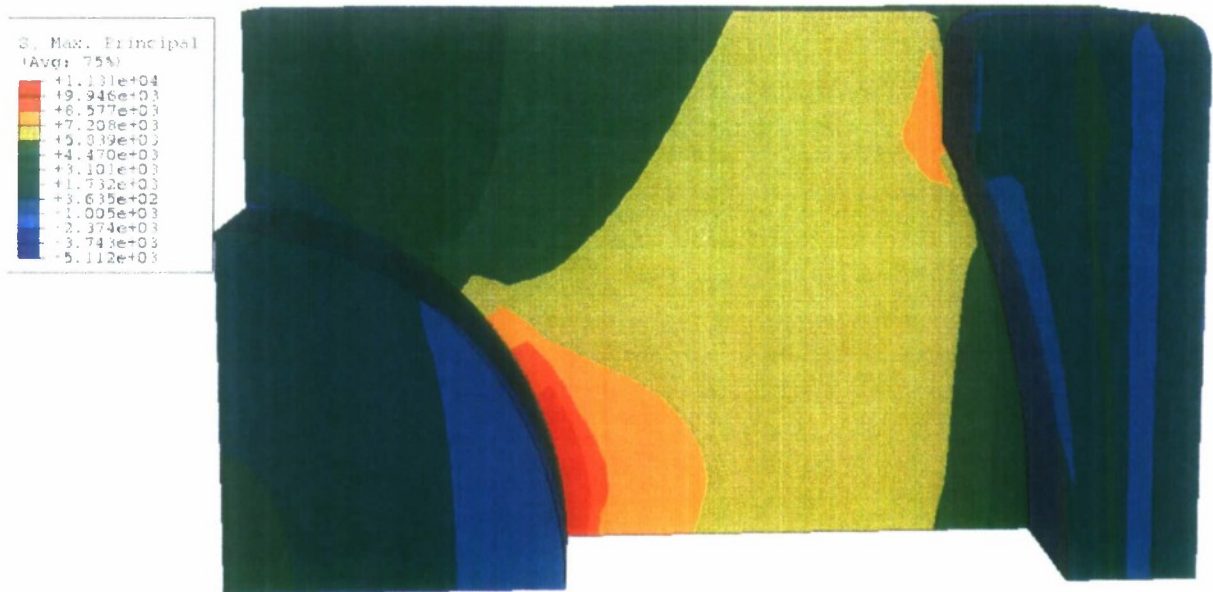


Figure 6. The third 4-Point bend test with top displacement of 0.00025 in., resulting in 0.00056 in. of displacement on bottom center.

5. Conclusions

A finite-element analysis (FEA) was performed on a ferrite core part. A 3-point bend test and three different geometries of 4-point bend tests were modeled to determine the distribution of tensile stress on the bottom of the part. The objective of the FEA was to understand the tensile stress distribution under simple 3- and 4-point bend loading conditions that would be easily implemented as a proof test.

The ideal test scenario generates a minimum stress gradient to achieve nearly uniform stress levels throughout the entire tensile surface of the part. The simulations indicate that the largest tensile stress is between 18.8 and 11.3 ksi. For the molding defect location, the calculated stresses for these two scenarios are approximately 0.27 and 0.53 of this maximum, respectively. Because these are relatively small fractions of the maximum, it is unlikely that these loading scenarios could function as proof tests. For failure to occur in the molding defect location or along an edge of the part at a chip out, the strength of the defect would have to be much smaller than the strength of the corner between the central disk and the as-sintered surface.

The location of the predicted maximum tensile stress was corroborated by the failure locations in the two three-point bend tests that were performed. According to the model, the failure load was equivalent to a tensile stress of approximately 15 ksi. At the time of failure, the molding defects in the part were under a tensile stress of approximately 4 ksi. In either the three- or four-point bend test configuration, the failure location would need to sustain a significantly higher load in order for the stress at the defect location to approach 15 ksi. Our experience in strength testing these ferrite cores in other testing configurations suggests that it is statistically unlikely that the parts could sustain a much higher load to induce failure at the defect location or along the edge. The stress distribution in the ferrite cores under different loading conditions in other applications will determine whether various fabrication and handling defects create a risk of cracking, fracture, or other structural failure. Should such a risk present itself, a more sophisticated proof test would be necessary.

PHYSICAL SCIENCES LABORATORIES

The Aerospace Corporation functions as an "architect-engineer" for national security programs, specializing in advanced military space systems. The Corporation's Physical Sciences Laboratories support the effective and timely development and operation of national security systems through scientific research and the application of advanced technology. Vital to the success of the Corporation is the technical staff's wide-ranging expertise and its ability to stay abreast of new technological developments and program support issues associated with rapidly evolving space systems. Contributing capabilities are provided by these individual organizations:

Electronics and Photonics Laboratory: Microelectronics, VLSI reliability, failure analysis, solid-state device physics, compound semiconductors, radiation effects, infrared and CCD detector devices, data storage and display technologies; lasers and electro-optics, solid-state laser design, micro-optics, optical communications, and fiber-optic sensors; atomic frequency standards, applied laser spectroscopy, laser chemistry, atmospheric propagation and beam control, LIDAR/LADAR remote sensing; solar cell and array testing and evaluation, battery electrochemistry, battery testing and evaluation.

Space Materials Laboratory: Evaluation and characterizations of new materials and processing techniques: metals, alloys, ceramics, polymers, thin films, and composites; development of advanced deposition processes; nondestructive evaluation, component failure analysis and reliability; structural mechanics, fracture mechanics, and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures; launch vehicle fluid mechanics, heat transfer and flight dynamics; aerothermodynamics; chemical and electric propulsion; environmental chemistry; combustion processes; space environment effects on materials, hardening and vulnerability assessment; contamination, thermal and structural control; lubrication and surface phenomena. Microelectromechanical systems (MEMS) for space applications; laser micromachining; laser-surface physical and chemical interactions; micropropulsion; micro- and nanosatellite mission analysis; intelligent microinstruments for monitoring space and launch system environments.

Space Science Applications Laboratory: Magnetospheric, auroral and cosmic-ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; infrared surveillance, imaging and remote sensing; multispectral and hyperspectral sensor development; data analysis and algorithm development; applications of multispectral and hyperspectral imagery to defense, civil space, commercial, and environmental missions; effects of solar activity, magnetic storms and nuclear explosions on the Earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation, design, fabrication and test; environmental chemistry, trace detection; atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions, and radiative signatures of missile plumes.



The Aerospace Corporation
2310 E. El Segundo Boulevard
El Segundo, California 90245-4609
U.S.A.